TM-1166
1640

Fermilab

# Response of the Saver Dipole Beam Tube to Single Phase Helium Pressure

George Biallas and David Barner

January 19, 1983

## Abstract

One Energy Saver Dipole Beam Tube (#MB 124211) was tested under static and pulsed pressure conditions. Under static pressure, permanent deformation started at about 125 psi and reached .006 inches across flats after 220 psi exposure. Final catastrophic collapse occurred at 325 psi. Pressure pulses of shape and duration approximating the single phase helium pressure during a full house quench had no effect on the tube (previously staticly pressurized to 220 psi) up to 285 psi and a slight yield effect at 305 psi. Repeated pulses at 305 psi appeared to cause little or no further yielding. When compared to static pressure effects the 305 psi pulse produced the same deflection as about 235 psi static pressure.

## Introduction

Thornton Murphy speculates that during a full house quench, with one Kautzky valve failed, the pressure rise may locally go to 240 psia in the single phase helium circuit of the Saver (see Figure 1). This was higher than previously thought and getting close to the estimated collapse pressure of the Saver Dipole Beam Tube. The following investigation was to determine the static pressure collapse pressure of the Tube and whether the pulse duration of a full house quench was short enough to be considered a

transient and not have the same metal moving effect as a static pressure equal to the pulse peak pressure.

Apparatus

The apparatus consisted of three major parts. The first was the beam tube simulation. An insulati rapped beam tube was placed inside a surplus, cut-off 22-foot coil. The coil and tube were placed inside a water filled vessel rated at 350 psi (see Figures 2, 3 and 4 and Picture 1). This duplicated service conditions. The second part (Figure 5 and Picture 2) was a borescope consisting of a lighted dial indicator which measured the tube across-flat dimensions. The dial indicator was read with a Brunson scope as the indicator was positioned at 6-inch intervals down the tube. The third part (Figure 6 and Picture 3) was the pressure pulse device consisting of a surplus hydraulic accumulator, pressure test gauge and valving system pressurized by a nitrogen cylinder. The pressure vs. time readout was acquired via a pressure transducer signal to a storage oscilloscope.

Borescope Details

Internal dimension was measured with a Brown and Sharp "finger" style dial indicator fitted with an extra long finger and mounted on a custom measurement probe. This finger changed the scale reading to 0.00258 inch per major scale division but correspondingly expanded the span of the instrument. Distance along the beam tube was repeated within ± 1/8 inch by positioning the probe via markings on the probe pipe. The dial indicator was "zeroed" by placing a short piece of beam tube over the measurement head. The zeroing was done before each reading set was taken to catch calibration error and compensate for wear in the probe feet.

When readings were repeated, these readings had a maximum deviation from one another of 0.2 unit and had no greater than 0.3 zero offset. Thus, the absolute dimension was within .5 units (or .0013 inches) of the reading.

Pressure Pulser Details

The pressure pulser works as follows: a known quantity of gas in a bladder, backed up by a gas cushion, is discharged through a hand operated ball valve to a pipe system containing two branches. The lower branch contains the gas/water interface. The object to be tested is filled with water and the water is pressurized by the gas during activation. The upper branch of the pipe system contains a ball valve, venting to atmosphere, and setable to reproducible settings.

To produce a 305 psi pulse, for example, the bladder is vented to atmospheric pressure and the gas cushion side of the bladder is filled to 310 psi. Then the bladder is filled to 340 psi and thus has about 30/340 of the accumulator tank's gas volume. The ball valve is opened rapidly, pressurizing the pipe system in about 150 msec. The peak pressure is determined by the bladder's volume and the pressure. The setting of the vent valve as well as the original volume ratio of bladder to gas cushion determines the duration of the gas pulse at high pressure. At low bladder to cushion ratios, the gas cushion backup nearly maintains the fill pressure up to the time of the bladder's exhaustion. Subsequently, the pressure rapidly declines, simulating the rapid fall-off of the single phase pressure pulse.

In practice, the "mushiness" of the water filled system precludes setting an isolated pulse system to the right parameters. Thus, the

correct pulse pressure for this experiment had to be "worked up to", starting from lower pressures and more open valve settings.

Pressure was read on a U.S. Gauge Test Gauge accurate to ±1.5 psi. It was zeroed before the test and calibrated after via a dead weight tester to be within those limits. The transducer was calibrated using the above test gauge and oscilloscope and was readable on the oscilloscope pictures to 5 psi and was calibrated within 10 psi.

Chronology of the Experiment

A zero pressure set of readings (horizontal and vertical) was first taken on the tube. At static pressures of 100, 150, 200 and 220 psi, bore tube readings were taken at 6 inch intervals. Vertical readings were taken at Ø psi after every excursion to determine permanent set due to yielding. The only horizontal reading after a pressure excursion, taken at zero pressure, was taken after 220 psi. Two-hundred twenty psi is within 80% of the estimated collapse pressure and nearly up to the maximum anticipated pulse pressure. We decided to stop static pressurization at this value.

A second phase of testing consisted of pulse tests at 245, 285 and 305 psi (see picture pages). No permanent deformation was seen as a result of the first two pressure pulses and a 1/5 unit permanent set was noticed after the first 305 pressure pulse in the vertical and a half unit additional set was observed after 5 more attempts. In the horizontal, (the dimension in which the tube finally failed) a 3/4 unit deformation was observed on the first 305 psi pulse but no additional deformation occurred during the remaining attempts at 305 psi. By extrapolating from Graph 1, one conclusion to reach about the 305 psi pulse pressure is that it is equivalent to static pressure of, say, 237 psi. However there was anomalous behavior of the

system during this pressure pulsing. Only two pulses (#1 and #5) of the seven attempts at 305 psi actually read 300+ psi at the transducer placed at the far end of the pipe. Others read as low as 160 psi even though the pulsing system was set up the same way for all. I suspected the lower pressures were a sign of yielding, but no change was observed in the horizontal reading from 305 psi pulse #2 through #7. In any case, the tube withstood the pulses with little or no damage.

The third set of readings were then taken to find the static pressure collapse pressure. Further pulse tests could have been taken, but interest was lacking since pulses far beyond those ever expected were taken with little or no damage. Failure occurred after several minutes at 325 psi. A 3-foot long portion of one side wall about 3 feet from the near end collapsed inward (see Pictures 4 and 5).

Evaluation

Failure of this tube is not a classic collapse to flat of a round tube or of a four sided tube. The coil inside diameter provides restraint such that the early signs of failure are just bending inward of the flat portion of the beam tube face in classic beam fashion. Final failure was when the flat went into fully plastic strain and pulled the curved portion of the tube in with it toward the center.

Some useful information may be obtained from plotting a force vs. deflection curve with readings taken where the final collapse initiated. This is shown in Graph 1. The curve shows that some permanent set starts at 125 psi or so with 220 psi static pressure creating about 2.5 units or .0065 total permanent set in the horizontal as well as vertical. I suspect a pulse at 200 psi would produce a smaller deformation if any at all.

First order extrapolation to other tubes of lesser thickness due to tolerance is accomplished by comparing this tested tube's thickness (.057) with the minimum thickness specified for 16 gauge (.060 inch) stainless steel in ASTM Specification #A 480 which is .054 inches. It may be assumed that stress level scales with the inverse of the square of the thickness and the deflection as the inverse of the cube of thickness for elastic cases.

The slope of the elastic portion of the curve of Graph 1 decreases as $.054^3/.057^3 = .85$ and the stress level increases at a constant pressure as $.057^2/.054^2 = 1.11$. So, the knee of the curve should start bending over 10% sooner and I speculate failure should be at 325 psi x .90 = 292 psi.

Superimposed on the above data is that the yield strength of the material may vary from sheet to sheet. The material is 304 N stainless steel which has better properties than 304. The difference between the average and the minimum properties of 304 at room temperature from one characterization[1] is 1.7%.

All of the above lead toward collapse or deformation at lower pressures than those of the experiment. However, the environment of the actual pressure pulse is at liquid helium temperature. Data from the above set of characterizations of 304 stainless steel indicate increases in yield strength of 25% for cold roller material and 95% for fully annealed material. Since these increases swamp any of the above extrapolation values I believe the results of this experiment are conservative characterizations of even the worst case of tube thinness and low strength.

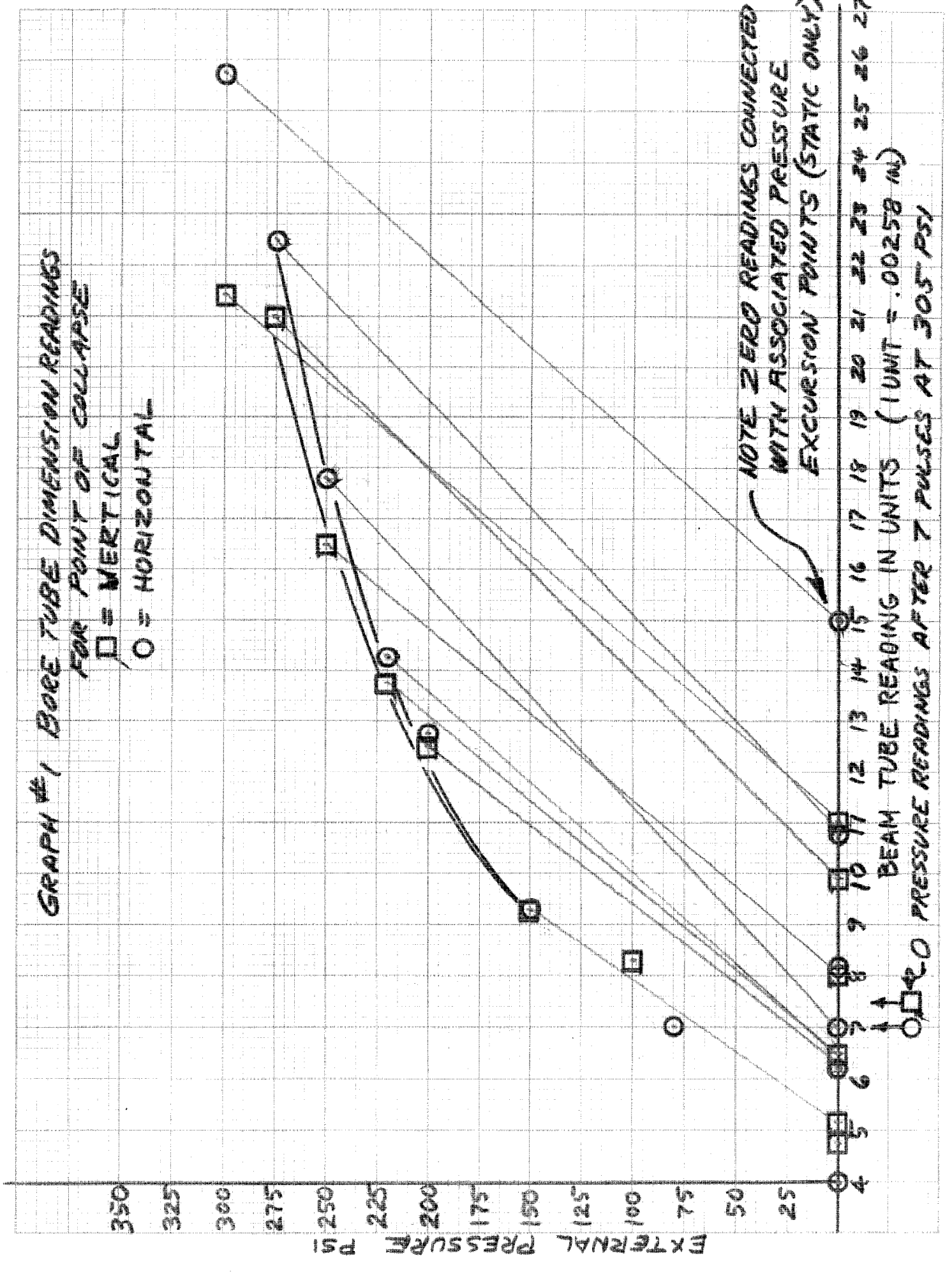
Note that collapse occurred opposite to the seam weld. Graph 1 also has some additional information contained in it. I explain the reverse slope of the vertical curve at low pressures as the settling out of the square tube

[1] Handbook on Materials for Superconducting Machinery, Metals and Ceramics Information Center, Battelle Columbus Laboratory, Nov. 1974, Table 8.1.2-ME[2]

to a diamond configuration, touching two corners against the coil I.D. The anomalous vertical point at 300 psi is a result of the severe inward deflection in the sides of the tube bending the top and bottom almost back out. Intermediate levels of pressure produce remarkably smooth curves for both horizontal and vertical readings.

Conclusions

At the levels of pressure anticipated in the Saver, the beam tube should never be a collapse problem. A conservative statement is that pressure pulses of the Saver are brief enough to effect the beam tube as if a static pressure of 77% of the pulse value was imposed.


GRAPH #1 BORE TUBE DIMENSTROM READINGS
FOR POINT OF COLLAPSE
□ = VERTICAL
○ = HORIZONTAL
NOTE ZERO READINGS CONNECTED
WITH ASSOCIATED PRESSURE
EXCURSION POINTS (STATIC ONLY)
BEAM TUBE READING IN UNITS (1 UNIT = .00258 IN.)
0 PRESSURE READINGS AFTER 7 PULSES AT 30 PSI
EXTERNAL PRESSURE PSI
350
325
300
275
250
225
200
175
150
125
100
75
50
25
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27

## Pressure extrapolations to 4440 A

**Cryostat:**

$I^2$ extrapolation

eyeball fit of straight line to the data

168 - 185 psig at relief valve

198 - 215 psia in cryostat / +15 for Δ P
+15 to absolu

from Kautzky rel. transducer to deep in cryostat

228 - 245 psia if 1 relief valve fails (+30)

Biallis: cryostat OK to 275 psia (bore tube collapse.

**Header system:**

90 ± 5 psig

Misek: header safe to 105 psig

Mulholland: rating = 100 psig

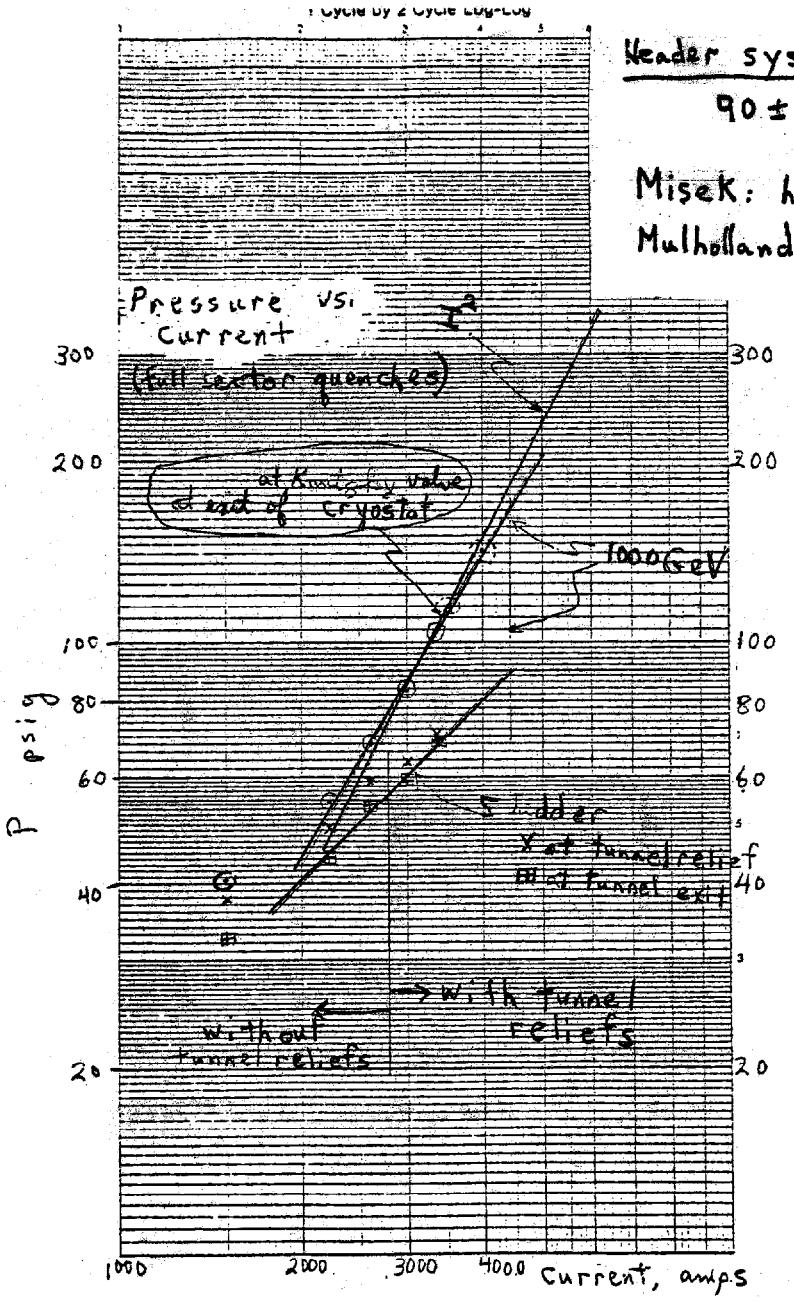


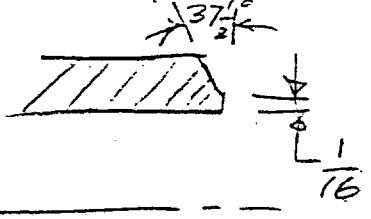

FIGURE 1

# FIGURE 2

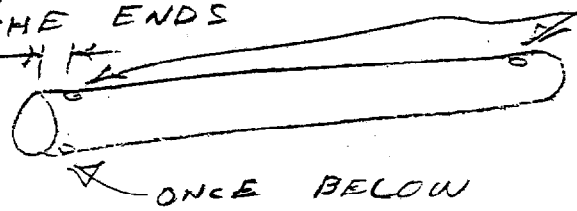
## MODIFICATIONS TO PARTS FOR BEAM TUBE PRESSURE TEST

11/17/82

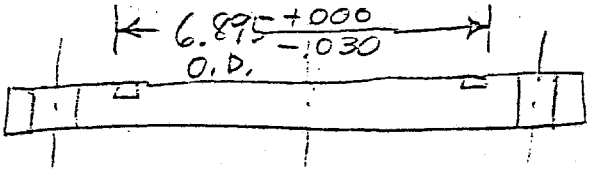
1. CUT 6" PIPE TO 24±1 INCHES, BEVEL EDGE FOR WELD PREP, BOTH ENDS



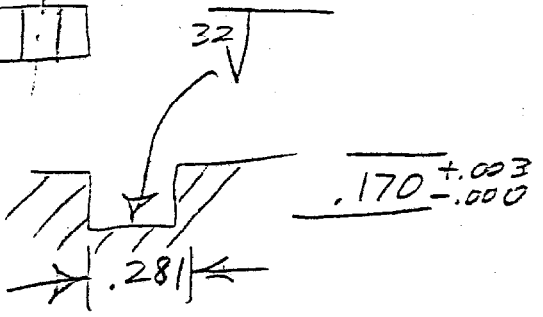

DRILL 1/2 DIA HOLE THREE PLACES
3" FROM THE ENDS




2. FACE OFF ALL FLANGES TO FLAT FACE. (BLIND FLANGES & WELD NECK)
3. MACHINE O-RING GROOVE IN BLIND FLANGES AS BELOW

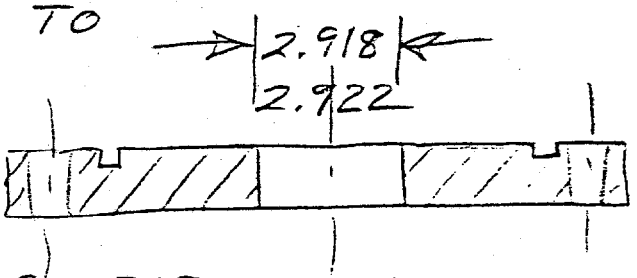



PARKER # 2-367 20A




+.005
-.000

4. SUPPLY 6 BARS 3/4 SQ x 11" LONG - STEEL
4A. WELD UP UNIT - SEE ADDITIONAL SHEET
5. AFTER PIPE PRESSURE TEST, BORE THE BLIND FLANGES TO

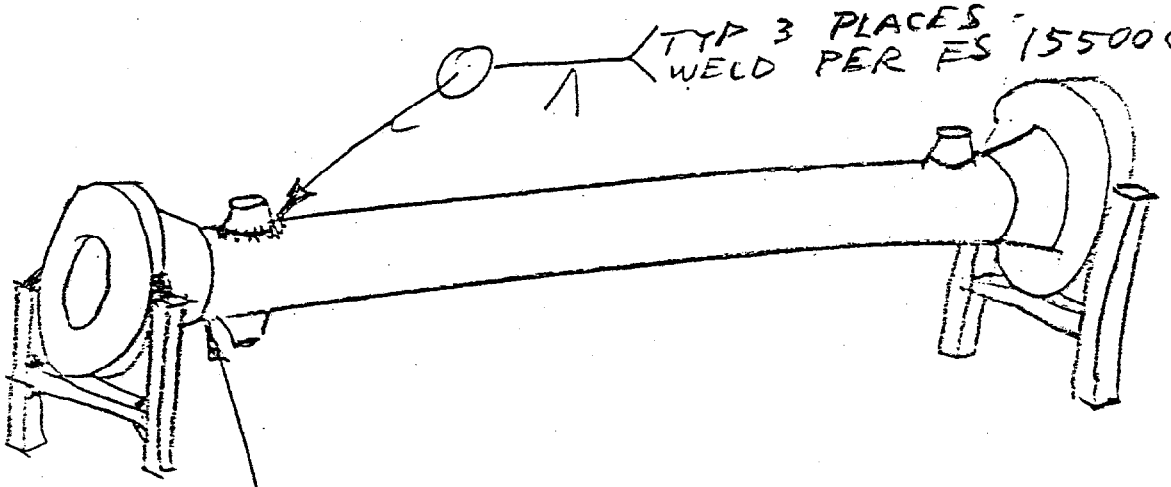



6. SUPPLY 18 PIECES AS BELOW

MATERIAL; STAINLESS STEEL

# FIGURE 3

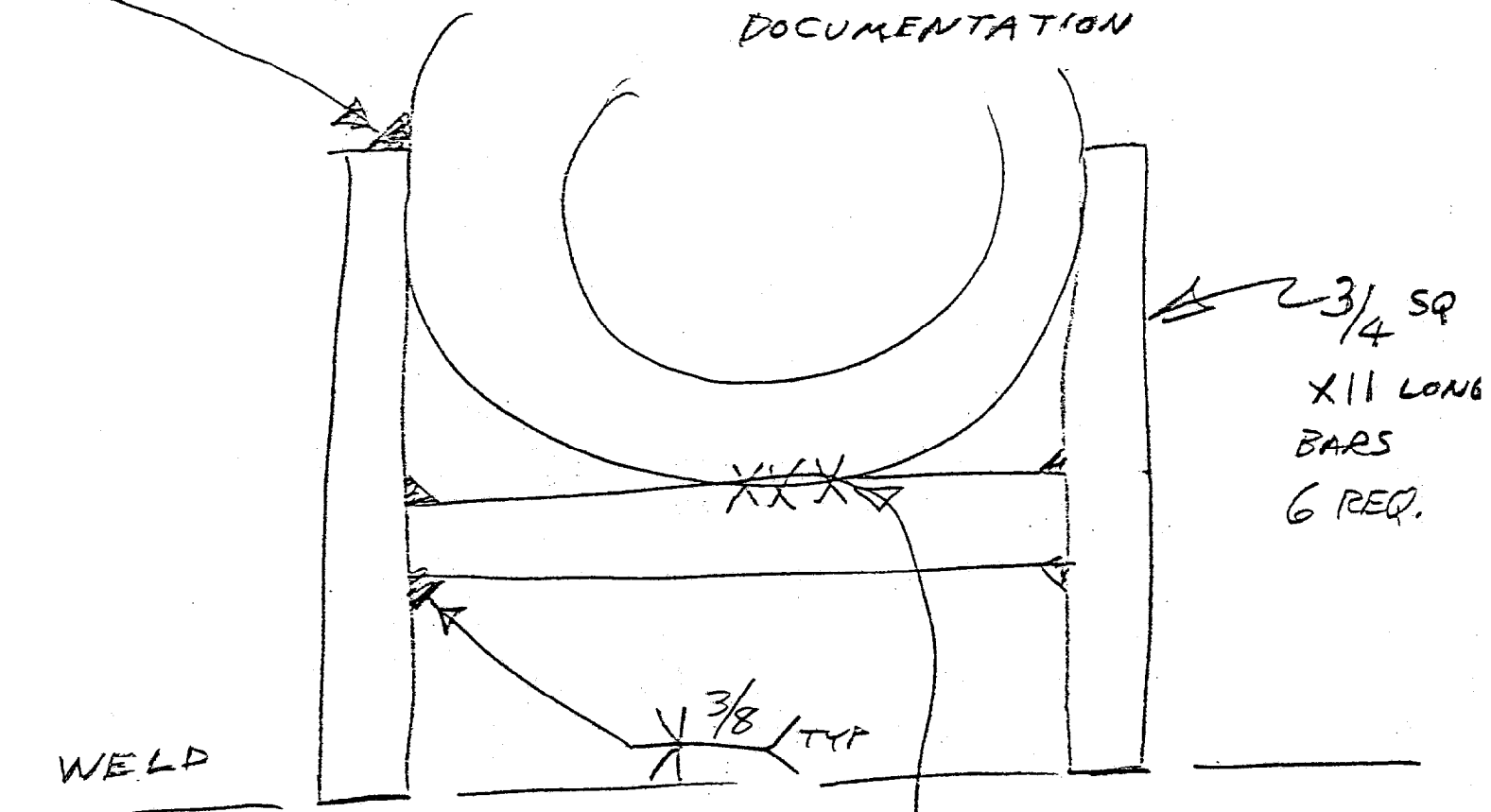
## PRESSURE TANK FOR BEAM TUBE TEST




TYP BOTH ENDS
WELD PER ASME WELD PROCEDURE
ES 155000 - SUPPLY DOCUMENTATION

TYP. DON'T WELD ON FLANGE FACE

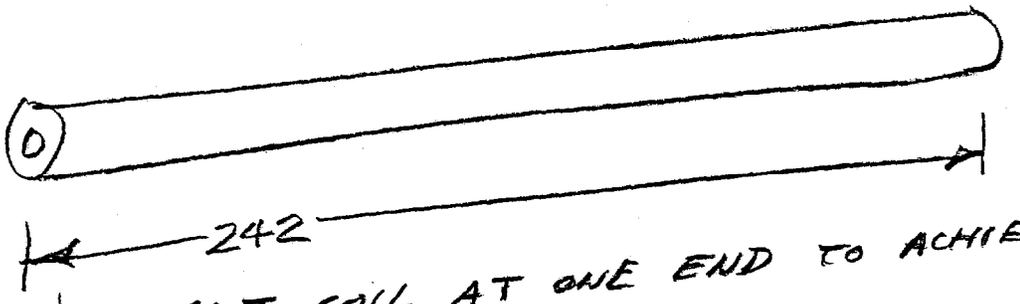
5/8



# FIGURE 4

22' COIL MODIFICATIONS FOR BEAM TUBE PRESSURE TEST

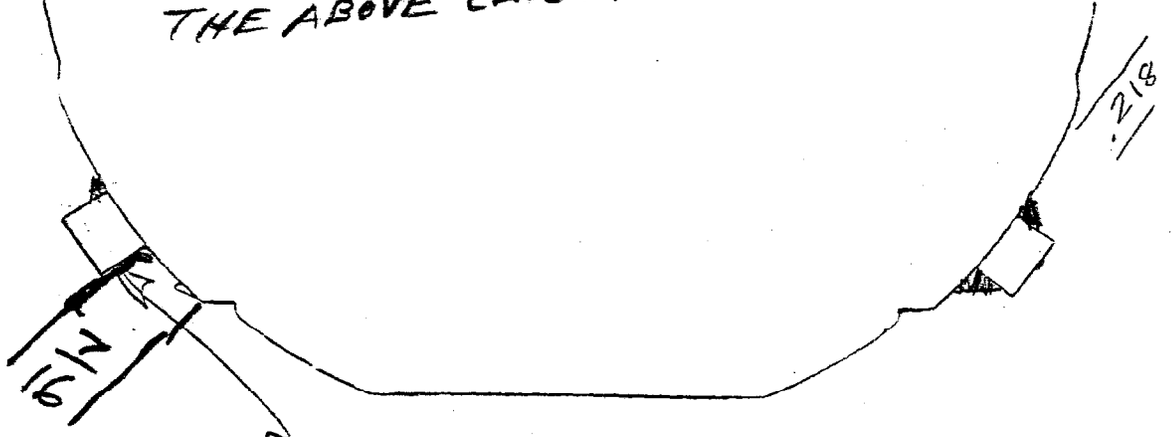
1.



242

CUT COIL AT ONE END TO ACHIEVE THE ABOVE LENGTH

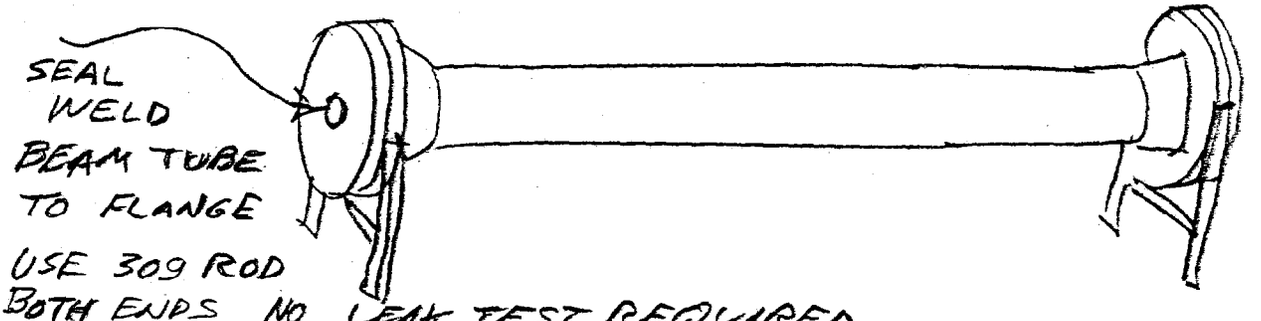
2.




TACK WELD SPACERS ON COIL BOTTOM AT 9 SUSPENSION LOCATIONS

3. INSERT COIL IN TANK AND MOUNT BEAM TUBE THROUGH COIL AND BLIND FLANGES.

4.

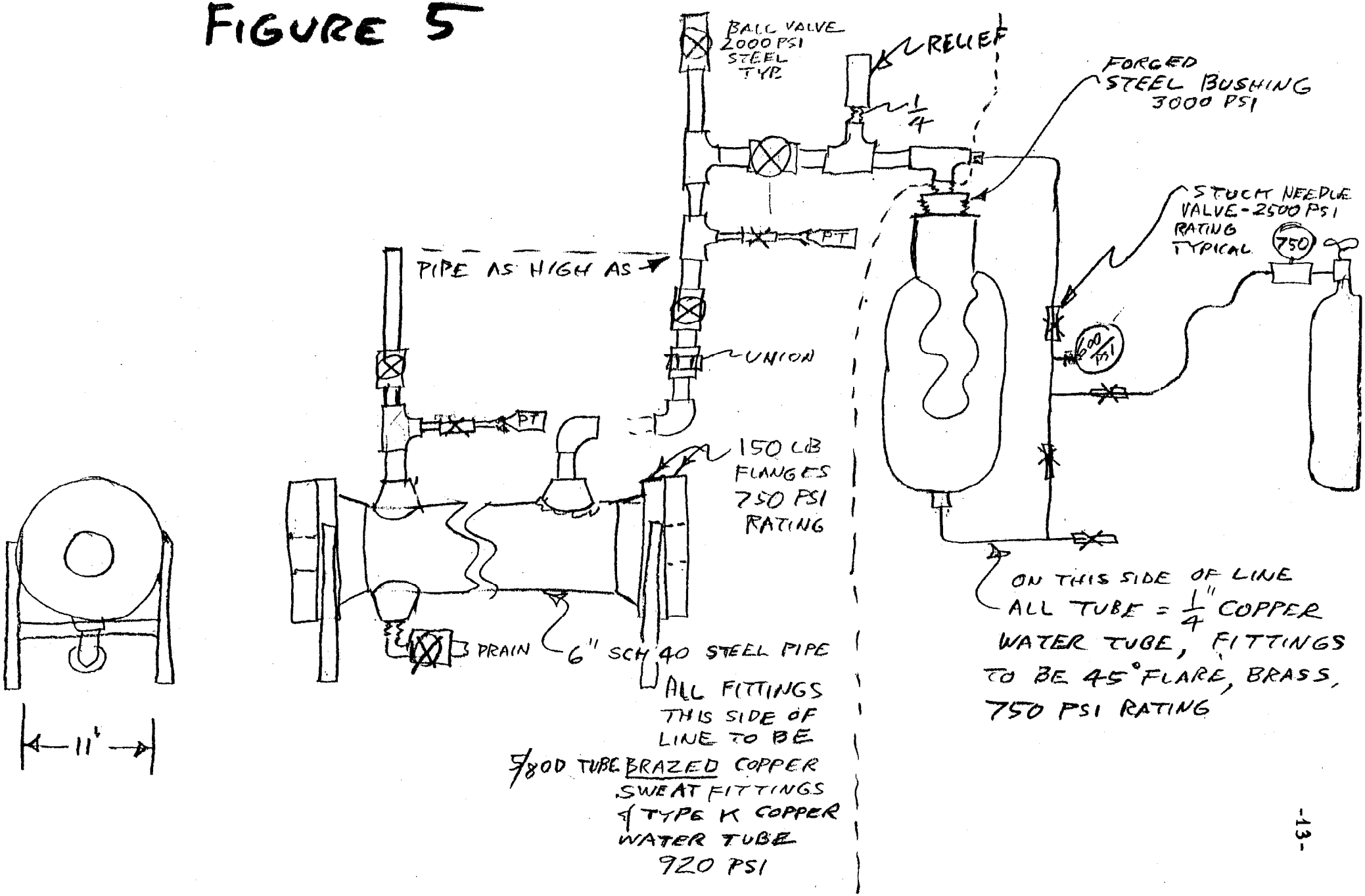



5. SHIP TO PROTO MAIN FOR TEST

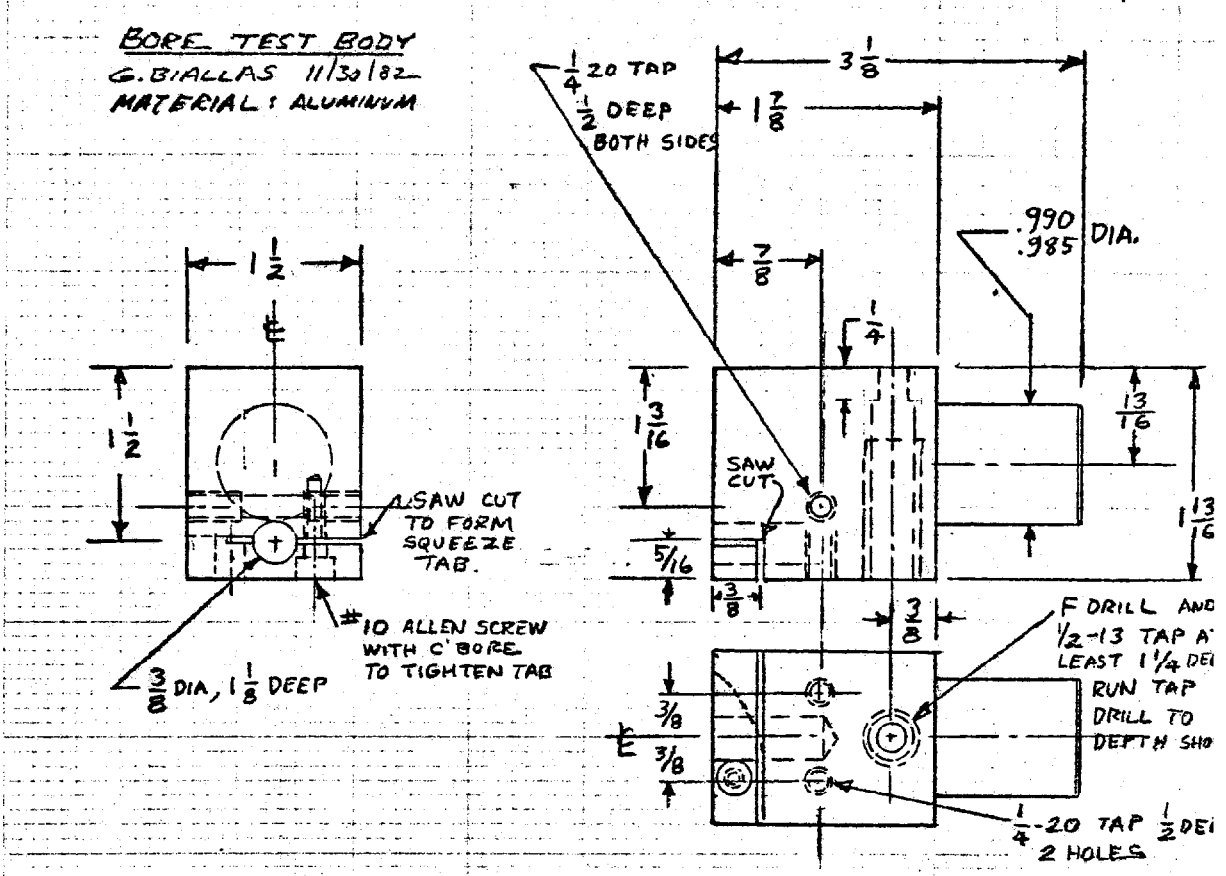
# FIGURE 5

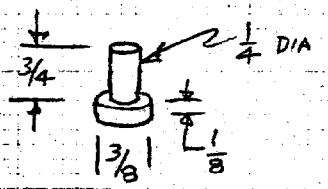
## CONFIGURATION OF BEAM TUBE
## PULSE PRESSURE TEST

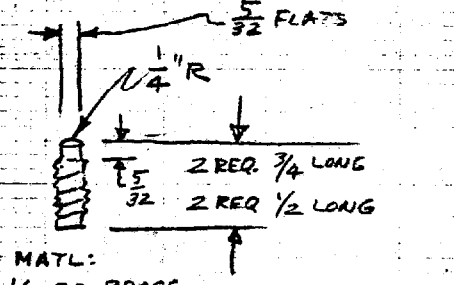
**750 PSI Maximum Pressure**

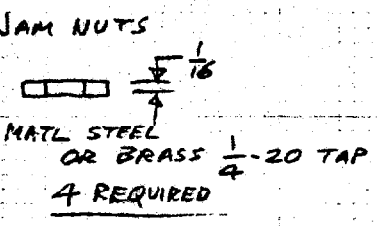


# FIGURE 6

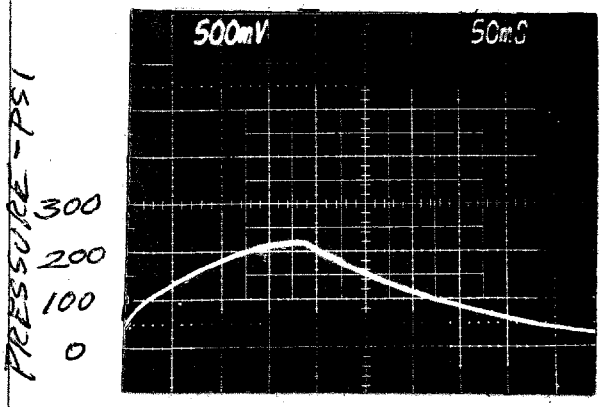

BORE TEST BODY
G. BIALLAS 11/30/82
MATERIAL: ALUMINUM
1/4 20 TAP
1/2 DEEP
BOTH SIDES
3 1/8
1 7/8
.990
.985 DIA.
7/8
1/4
1 1/2
1 1/2
1 3/16
13/16
SAW CUT
5/16
3/8
A. SAW CUT TO FORM SQUEEZE TAB.
#10 ALLEN SCREW WITH C' BORE TO TIGHTEN TAB
3/8 DIA, 1 1/8 DEEP
3/8
3/8
3/8
F DRILL AND
1/2-13 TAP A
LEAST 1 1/4 DE
RUN TAP
DRILL TO
DEPTH SHO
1/4-20 TAP 1/2 DE
2 HOLES


1/4 DIA
3/4
3/8
1/8
DIA MATL. BRASS
PLUNGER ONE REQ.

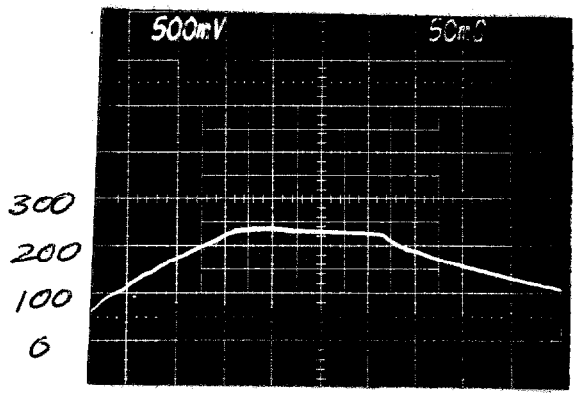

5/32 FLATS
1/4" R
5/32
2 REQ. 3/4 LONG
2 REQ 1/2 LONG
MATL:
1/4-20 BRASS
THREADED STOCK OR BOLTS
STAND OFF PADS


JAM NUTS
1/16
MATL STEEL
OR BRASS 1/4-20 TAP
4 REQUIRED

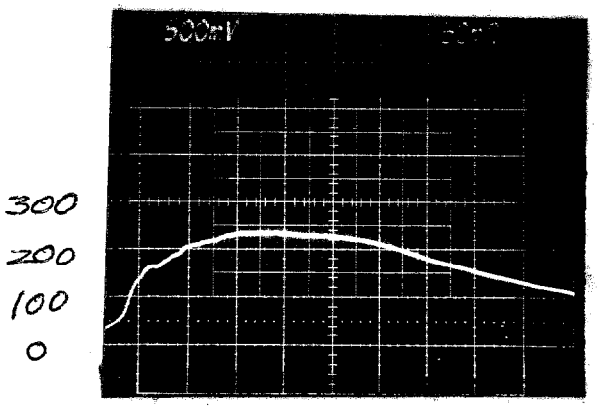
# PRESSURE PULSE RECORDS SHEET #1



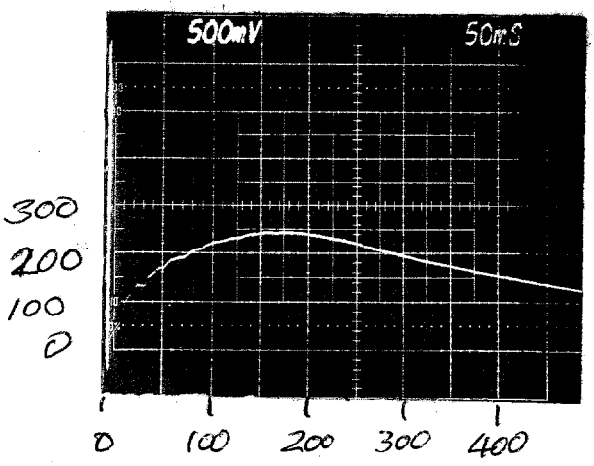

#1 220 PSI




#2 235 PSI

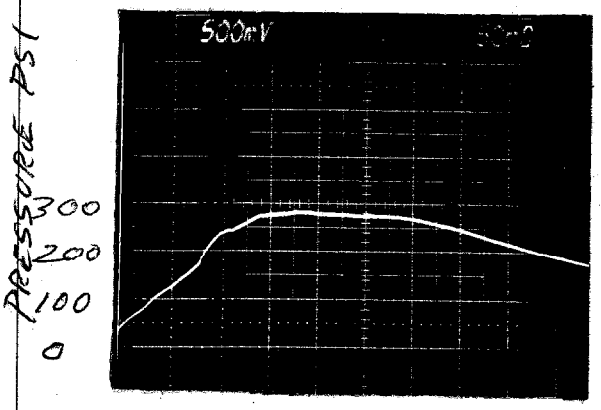



#3 235 PSI

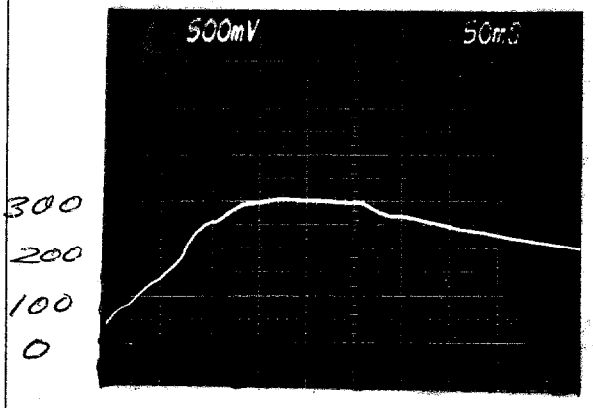



#4 245 PSI

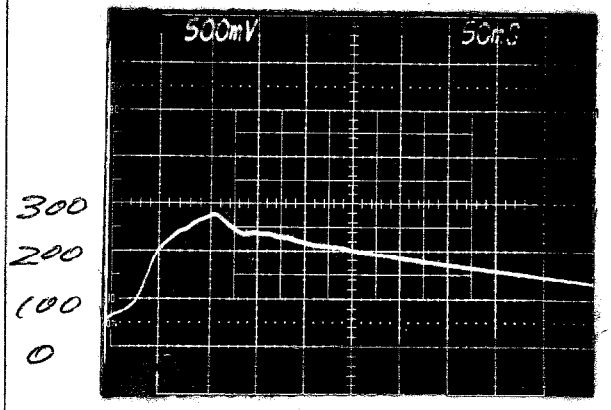
# PRESSURE PULSE RECORDS SHEET # 2



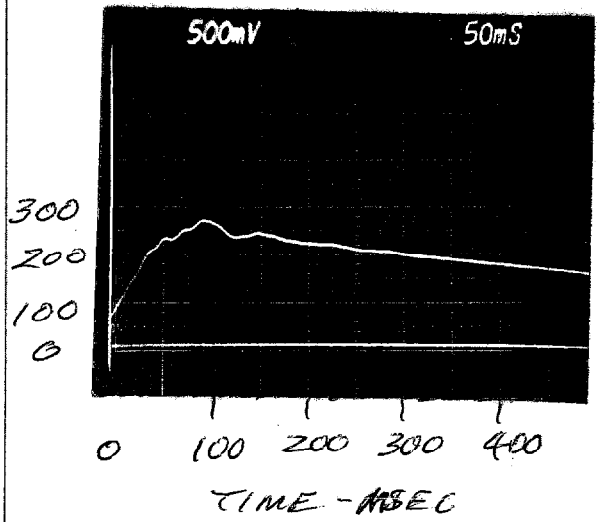

#5 285 PSI




#1 OF 7 305 PSI



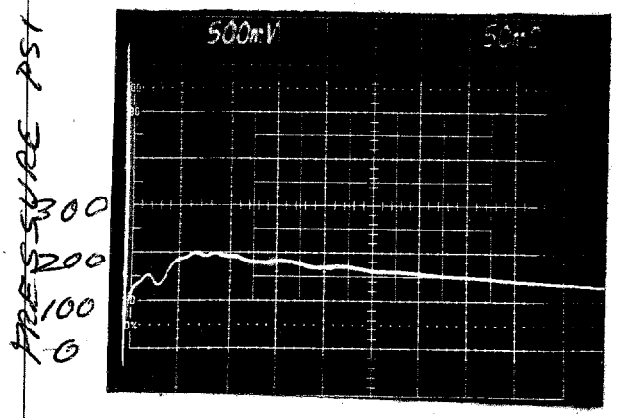

#2 OF 7 ATTEMPT AT 305



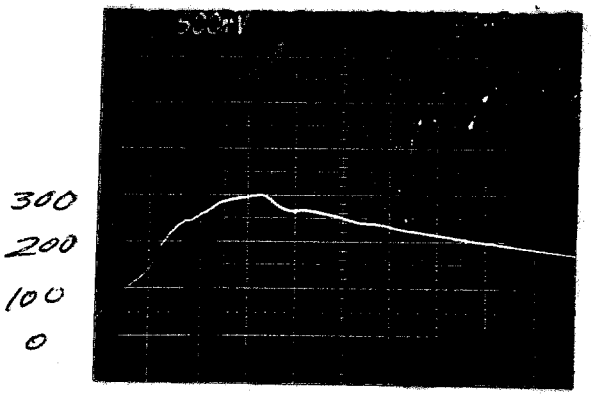

#3 OF 7 ATTEMPT AT 305

# PRESSURE PULSE RECORDS SHEET #3

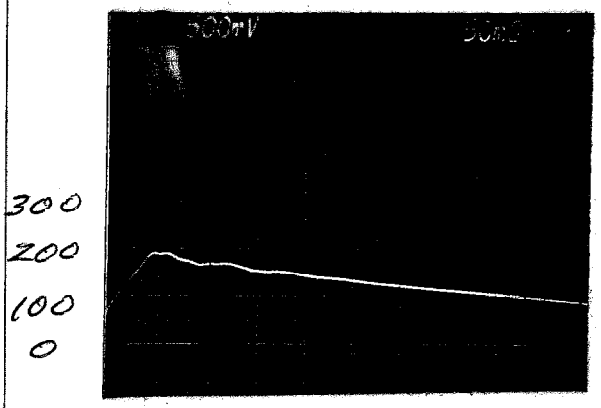




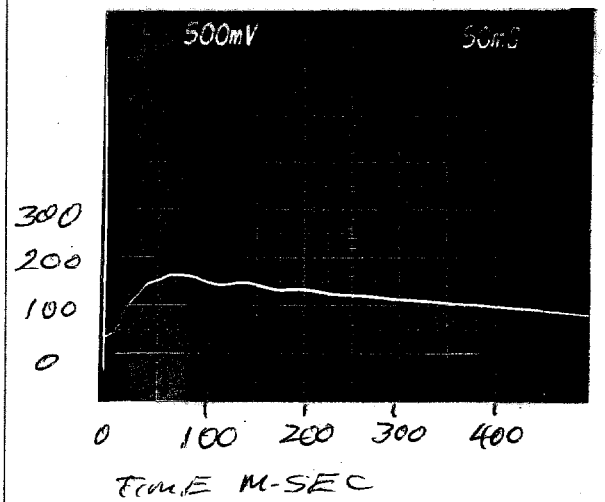

#4 OF 7 ATTEMPT AT 305 PSI



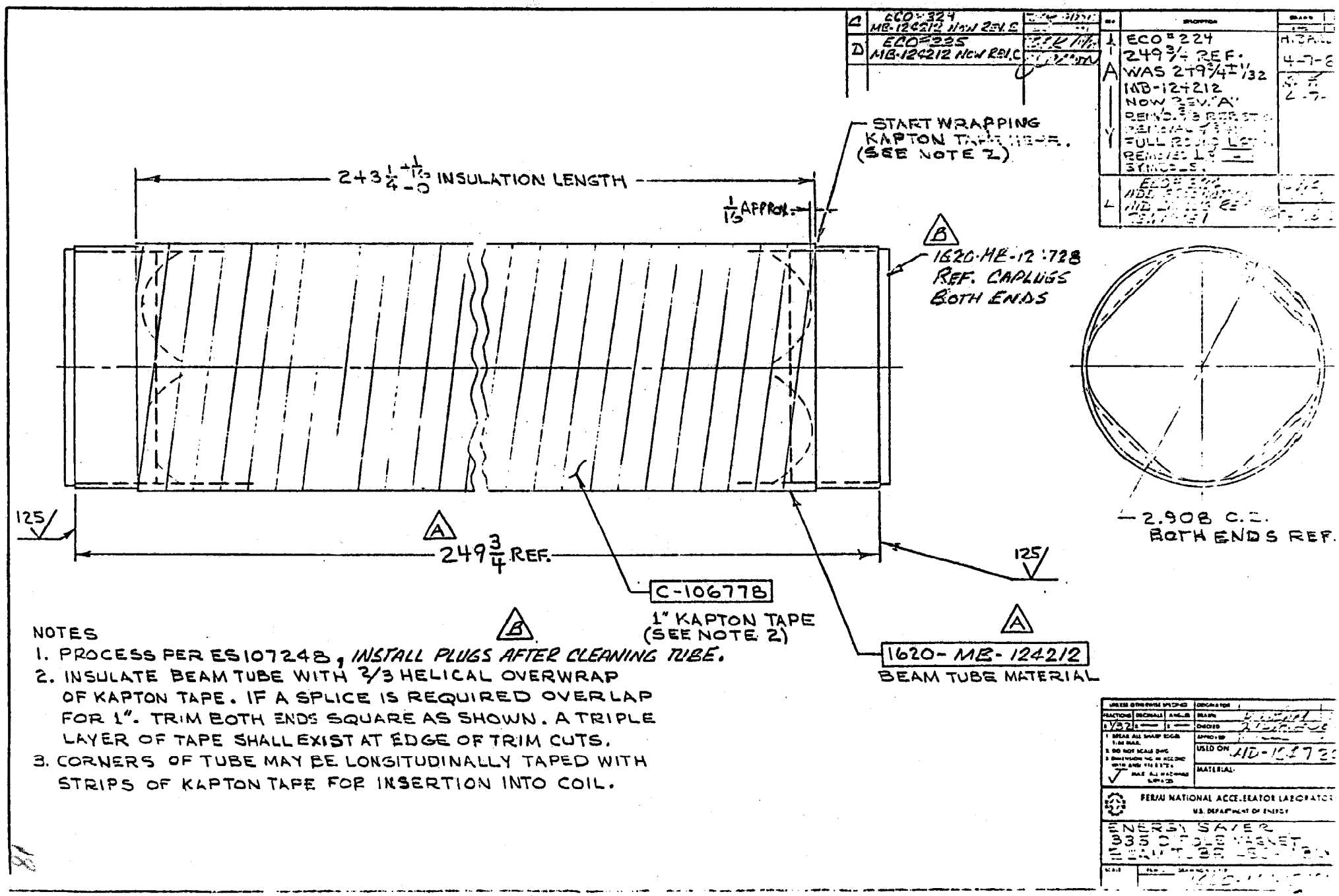

#5 OF 7 ATTEMPT AT 305 PSI




#6 OF 7 ATTEMPT AT 305 PSI



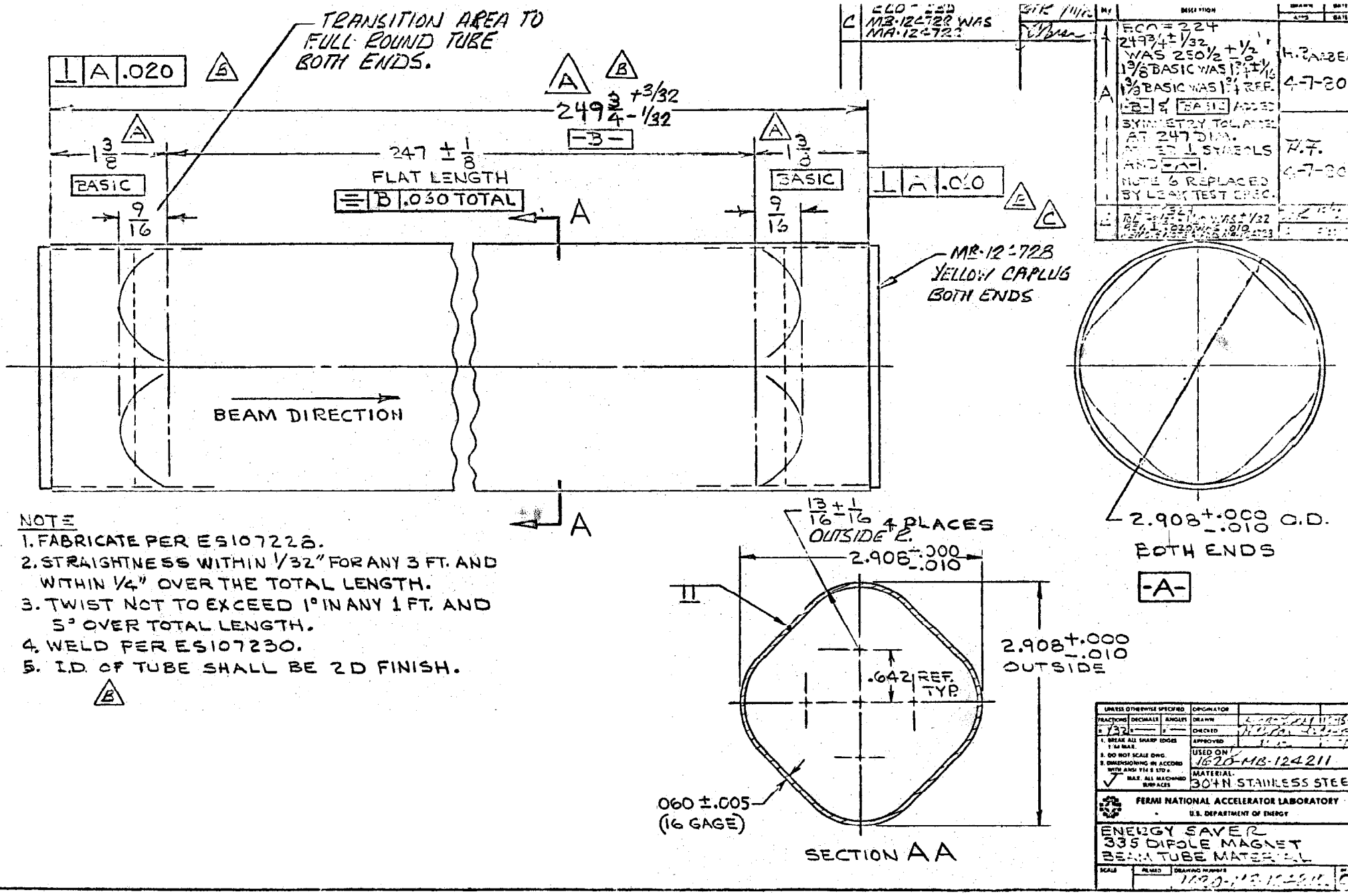

#7 OF 7 ATTEMPT AT 305 PSI

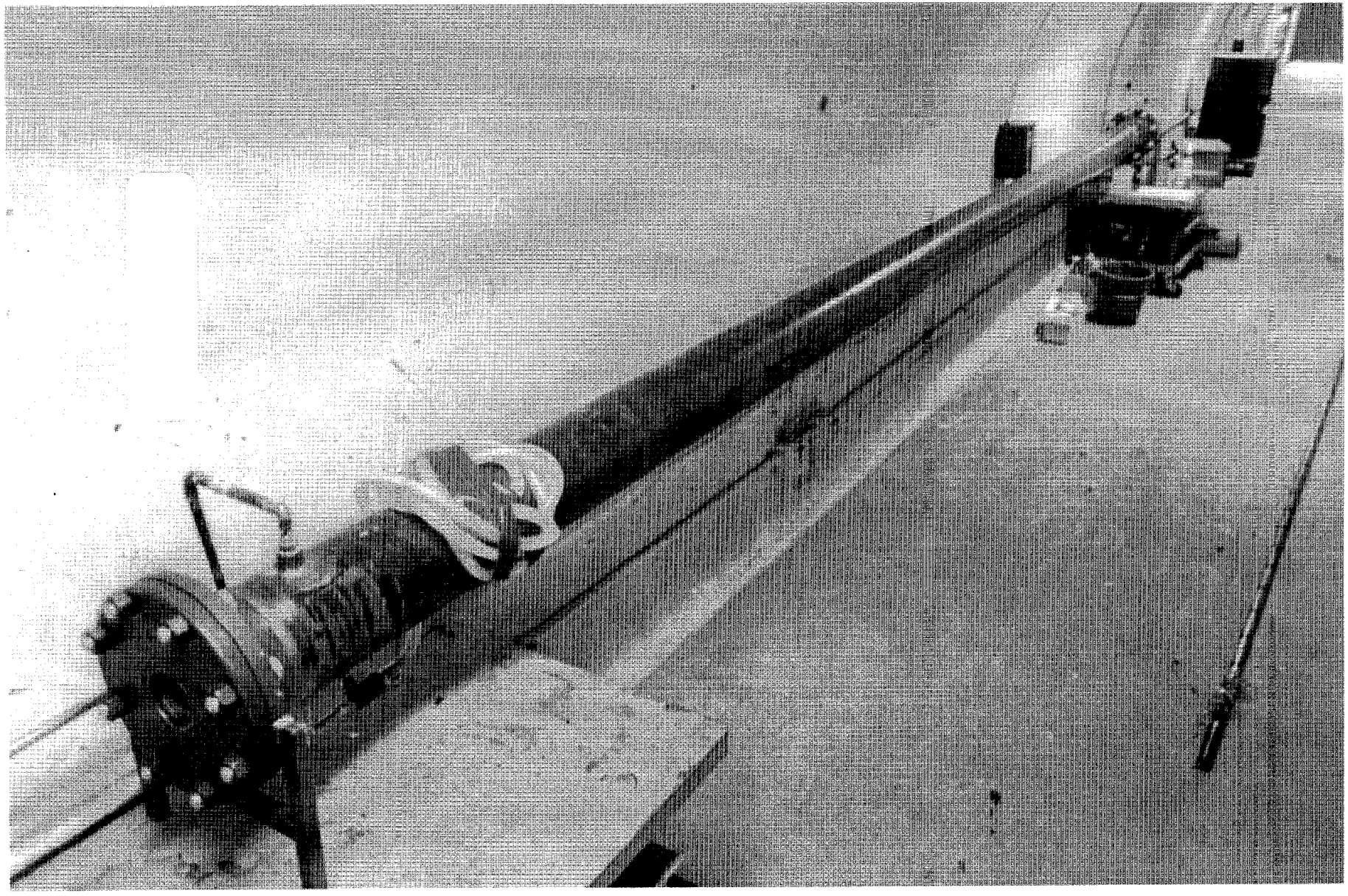



NOTES

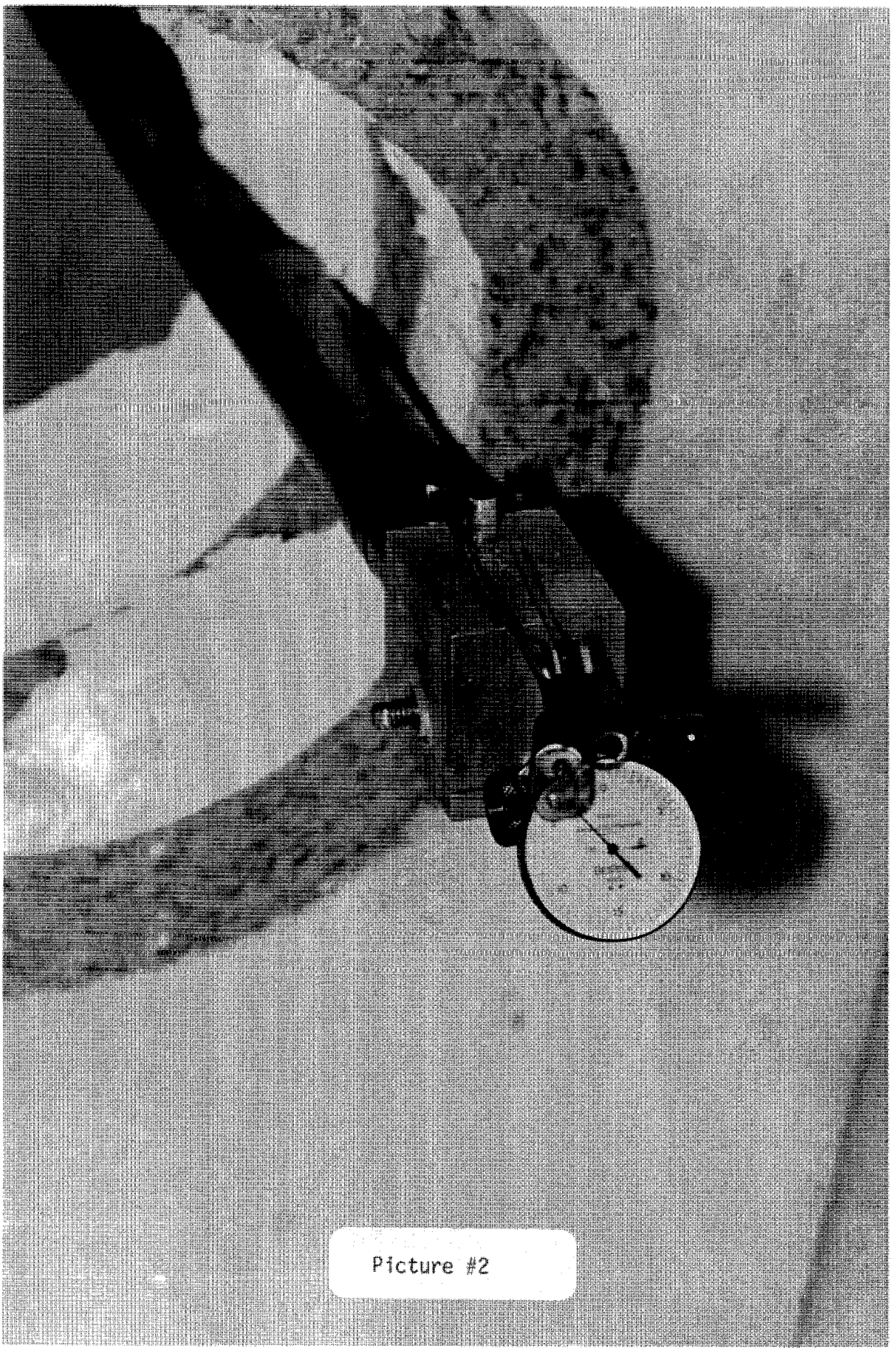
1. PROCESS PER ES107248, *INSTALL PLUGS AFTER CLEANING TUBE.*
2. INSULATE BEAM TUBE WITH 3/3 HELICAL OVERWRAP OF KAPTON TAPE. IF A SPLICE IS REQUIRED OVERLAP FOR 1". TRIM BOTH ENDS SQUARE AS SHOWN. A TRIPLE LAYER OF TAPE SHALL EXIST AT EDGE OF TRIM CUTS.
3. CORNERS OF TUBE MAY BE LONGITUDINALLY TAPED WITH STRIPS OF KAPTON TAPE FOR INSERTION INTO COIL.

FERMI NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY
ENERGY SAVER
333 D TRIPLET MAGNET
END TUBE

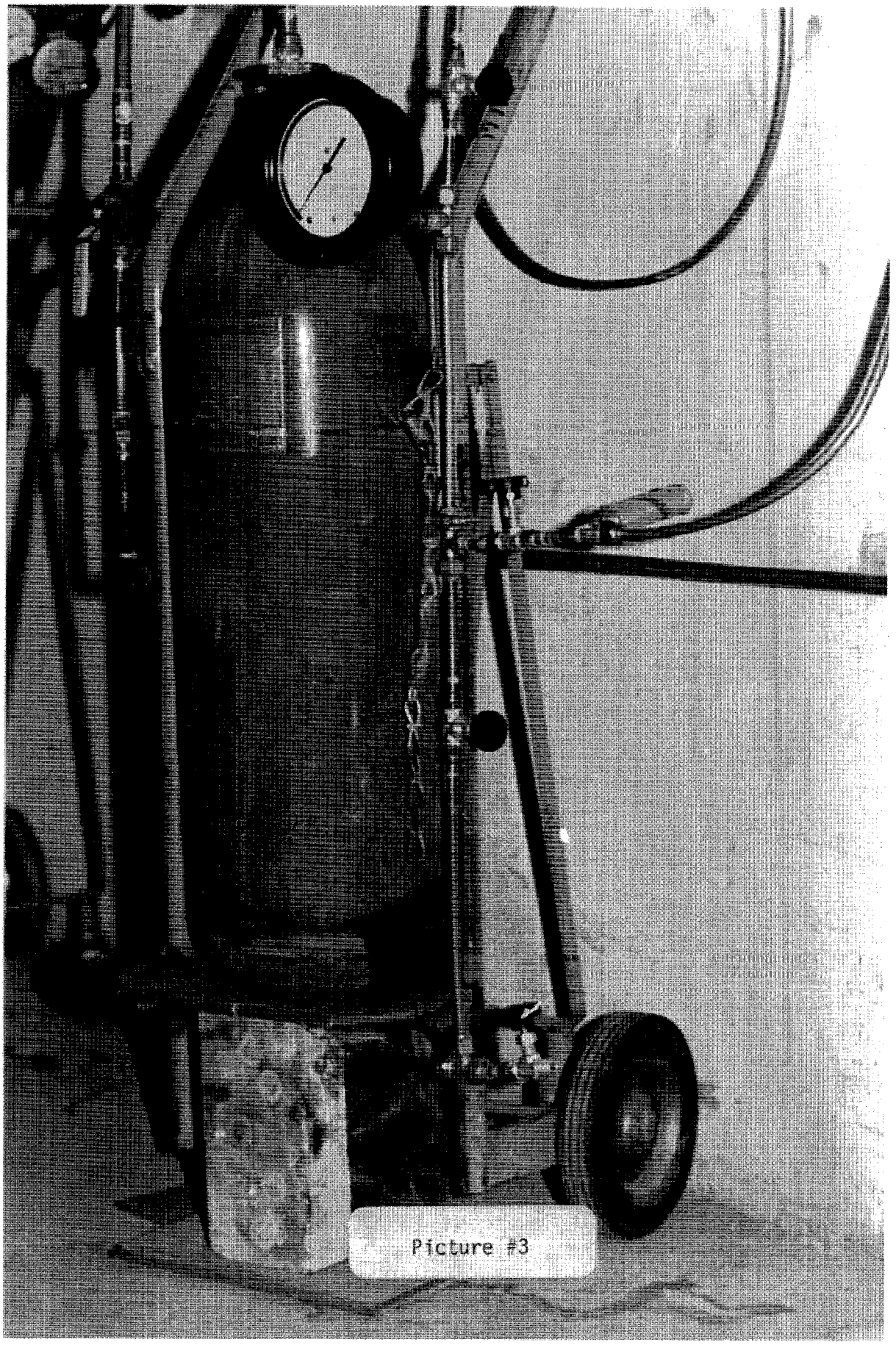

TRANSITION AREA TO FULL ROUND TUBE BOTH ENDS.
⊥ A .020
249 3/4 +3/32 -1/32
-B-
1 3/8
BASIC
247 ± 1/8
FLAT LENGTH
B .030 TOTAL
9/16
A
MB-124728 YELLOW CAPLUG BOTH ENDS
BEAM DIRECTION
NOTE
1. FABRICATE PER ES107228.
2. STRAIGHTNESS WITHIN 1/32" FOR ANY 3 FT. AND WITHIN 1/4" OVER THE TOTAL LENGTH.
3. TWIST NOT TO EXCEED 1° IN ANY 1 FT. AND 5° OVER TOTAL LENGTH.
4. WELD PER ES107230.
5. I.D. OF TUBE SHALL BE 2D FINISH.
13/16 ± 1/16 4 PLACES OUTSIDE R.
2.908 +.000 -.010
2.908 +.000 -.010 OUTSIDE
.642 REF. TYP.
.060 ±.005 (16 GAGE)
SECTION AA
2.908 +.000 -.010 O.D. BOTH ENDS
-A-
ECO = 224
249 3/4 ± 1/32 WAS 250 1/2 +1/2 -0
1 3/8 BASIC WAS 1 3/4 ± 1/16
1 3/8 BASIC WAS 1 3/4 REF.
-B- & BASIC ADDED
SYMMETRY TOL. ADDED AT 247 DIA.
ADDED ⊥ SYMBOLS AND -A-.
NOTE 6 REPLACED BY LEAK TEST SPEC.
H. BARBER 4-7-80
4-7-80
USED ON 1620-MB-124211
MATERIAL 304 N STAINLESS STEEL
FERMI NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY
ENERGY SAVER
335 DIPOLE MAGNET
BEAM TUBE MATERIAL



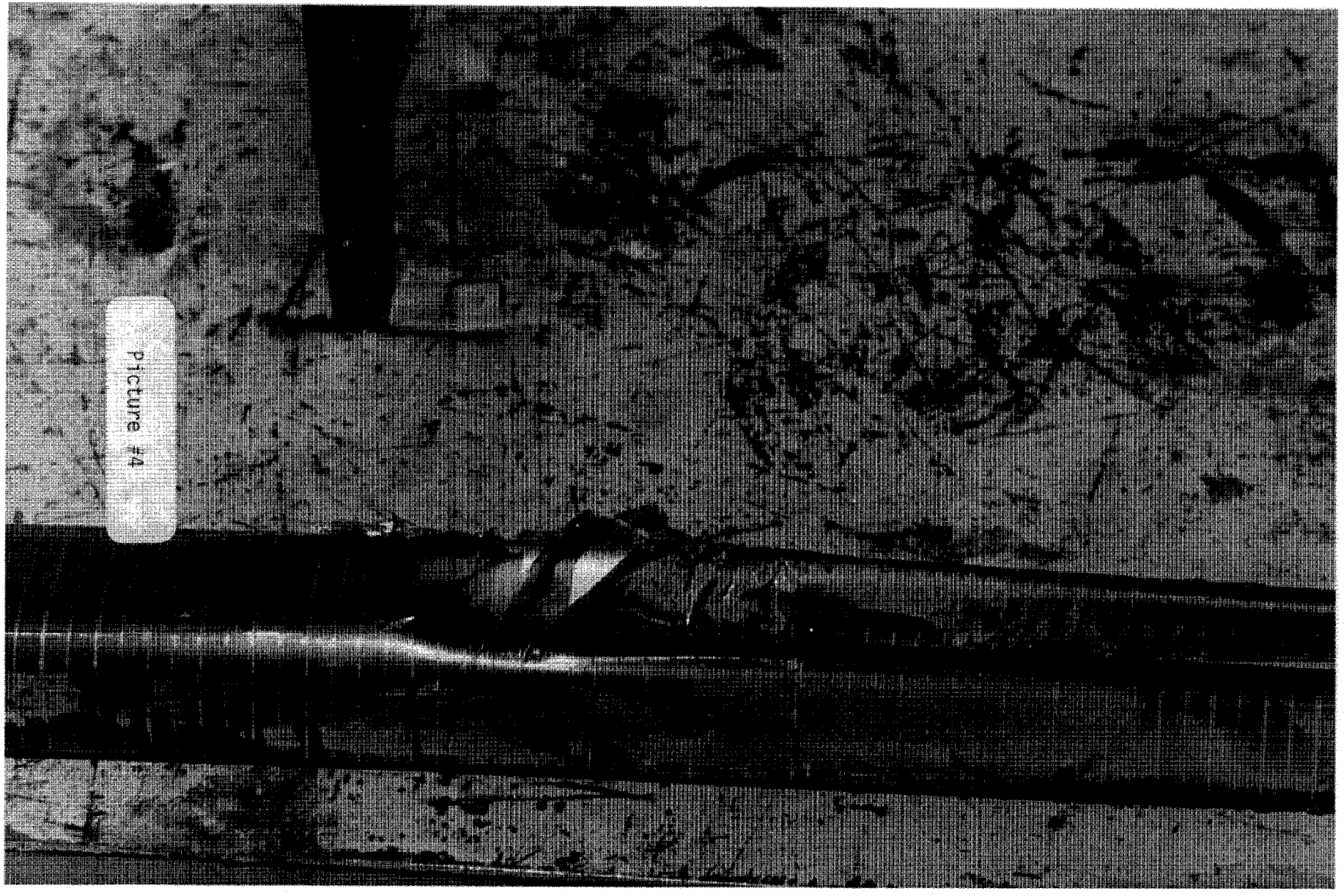
**PICTURE I**

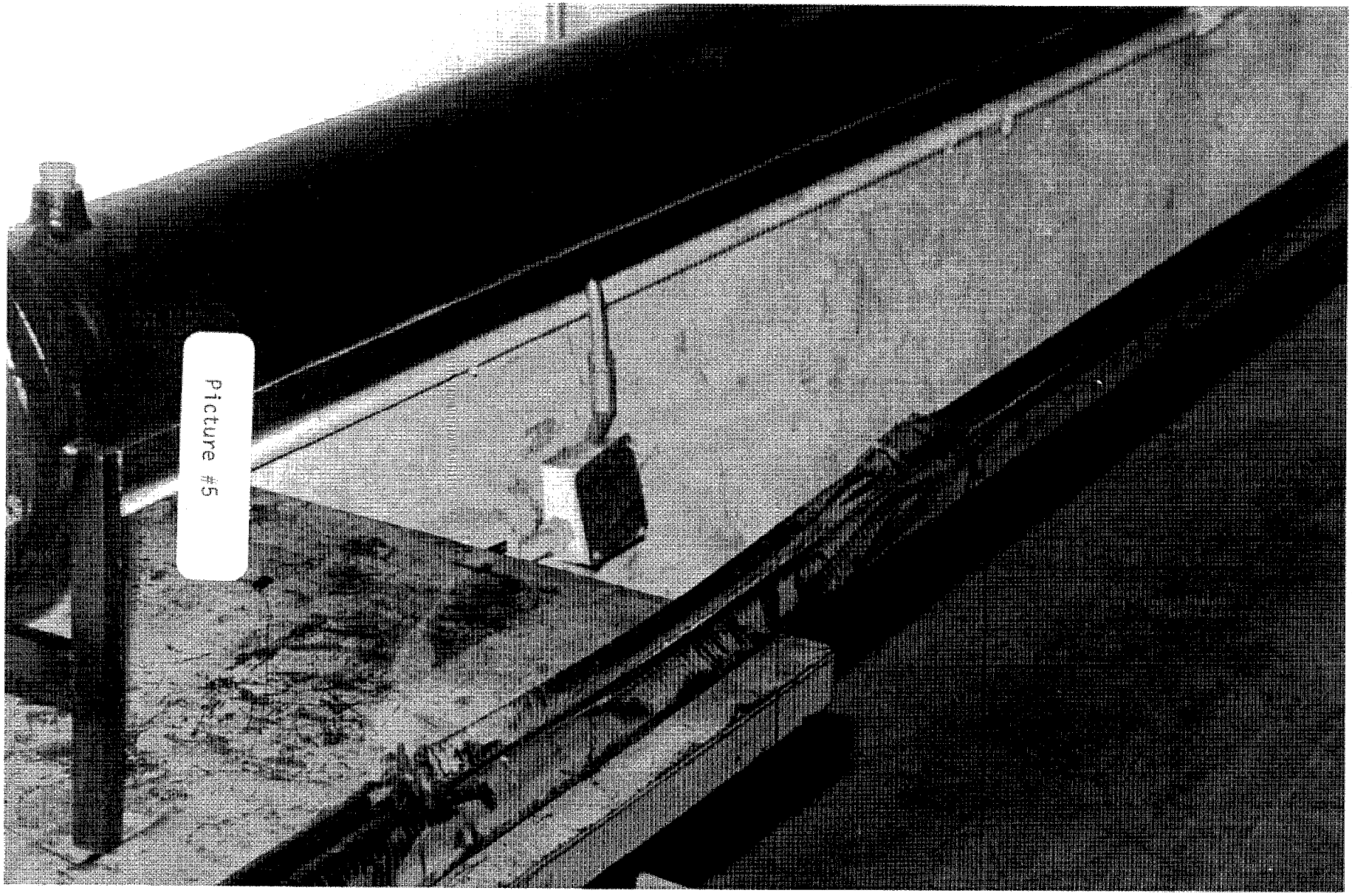


Picture #2



Picture #3


Picture #4


Picture #5